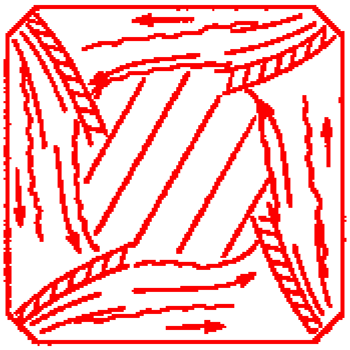
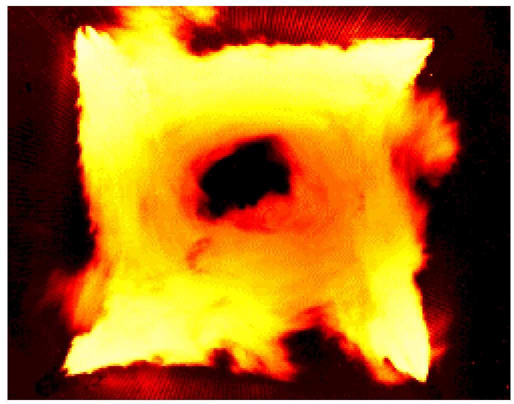
EPA/600/F-95/012
August 1995

Combustion Modification Control of Nitrogen Oxides, USEPA, Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC, EPA Report EPA/600/F-95-012, August 1995

Combustion Modification Control of Nitrogen Oxides

Taking Research from Concept to Implementation





An analysis of the impacts of EPA's NO_x control technology research on the environment

Introduction

EPA's efforts in research and development of nitrogen oxide (NO_x) control technologies by means of modifying the combustion process have played a major role in reducing stationary source NO_x emissions by over 3 million tons (2.73 x 10^6 tonnes) annually, and have led to at least three low NO_x burner technologies now commercially offered by major equipment vendors. These accomplishments have been made with an average total EPA investment of less than $4 million per year over the past 20 years.

NO_x formed during the combustion process has been seen as a major air pollution problem since environmental issues first rose to the national forefront less than 30 years ago. Since its inception, EPA has played a major role in the development of NO_x control technologies through research conducted and directed by the Agency. EPA has been involved in the full scope of technology development, from investigations of the fundamental science of NO_x formation to the full-scale field demonstration of new control technologies. These successful efforts have contributed to a reduction of NO_x emissions through the New Source Performance Standards (NSPS) and the 1990 Clean Air Act Amendments (CAAAs), both of which are based on combustion modification control of NO_x.[1] Research at EPA's Air and Energy Engineering Research Laboratory (AEERL) continues to develop more effective and efficient control technologies and to transfer those technologies to markets in both the U.S. and abroad.

Background

NO_x, which includes nitrogen oxide (NO) and nitrogen dioxide (NO_2), is an important pollutant for several reasons. NO_x is a primary contributor to ozone non-attainment, and it contributes to acid deposition, forest damage, and visibility problems in addition to direct adverse health impacts from NO_2. NO_x from stationary combustion sources is a major contribution to total emissions, and control of these emissions can result in significant improvements to the environment. However, control of NO_x is a complex process affected by the nitrogen content of the fuel, the amount and distribution of air in the combustion process, temperature, unit load, and burner design, among other factors. Therefore, NO_x emissions vary significantly with changes in temperature and air/fuel mixing, and are controlled primarily by modifying the basic combustion process, with the result that combustion modification NO_x controls directly affect not only emissions, but often the efficiency and operability of the unit as well. The need to minimize emissions and maximize operating efficiency then makes NO_x control a technically challenging endeavor that requires understanding of complex issues from combustion chemistry to plant operations, as well as an understanding of the economic issues related to plant fuel consumption and maintenance.

In the late 1960's and early 1970's, when environmental issues became more visible, little was known regarding the mechanisms of NO_x formation, particularly from the combustion of coal. The chemical and physical processes of pulverized coal combustion were not well understood, and the need to control the formation of NO_x added an additional layer of complexity to the problem. During the same period, energy efficiency also became increasingly important, leading to a large effort aimed at developing a better understanding of how pulverized coal burns. As a part of this effort, EPA sought to determine the mechanisms that govern the formation of NO_x during coal combustion as a basis for reducing NO_x emissions from utility boilers. EPA's early efforts focused on the prevention of NO_x through modification of the combustion process, since this approach held the promise of higher emissions reductions and greater economic efficiency than the use of flue gas treatment for NO_x control.

Research Accomplishments

Fundamental Research

One of the major accomplishments of EPA's NO_x program came out of the Fundamental Combustion Research (FCR) program. Work conducted by EPA personnel at EPA's Air and Energy Engineering Research Laboratory (AEERL) led to the discovery of the role of "fuel nitrogen" (i.e., nitrogen bound in the fuel) during the combustion of oil, synfuels, and pulverized coal.[2] This work not only determined the mechanisms for conversion of fuel nitrogen to NO_x, but it allowed for the development of low NO_x technology based on the principle of preferential conversion to molecular nitrogen (N_2) under fuel-rich combustion conditions. Based on the study of a wide range of U.S. and non-U.S. coals, it identified the need to maximize the volatilization of fuel nitrogen within the rich zone to enhance NO_x control.

This fundamental information made possible many of the subsequent combustion modification controls for NO_x from coal-fired boilers. Additional fundamental information developed under this program advanced the state of the art of technology development; EPA fundamental research on oxidative pyrolysis of nitrogen compounds also identified nitrous oxide (N_2O) as a major byproduct and hypothesized the N-C-O intermediate mechanism.[2] The importance of these developments was highlighted by a recent NO_x program review, during which experts in the field of NO_x control technology development noted that nearly all the advances in combustion modification NO_x control technology during the late 1980's and early 1990's were made possible by EPA-sponsored FCR during the 1970's. Thus the investments made 20 years ago continue to pay dividends toward a cleaner atmosphere.

Applied Research

Applied research sponsored by EPA on combustion modification NO_x control technology played a major role in the development of state of the art low NO_x burner technology designs. These designs, and other combustion modification NO_x controls, are based on creation of a fuel-rich primary zone to convert fuel nitrogen to N_2 rather than NO_x, followed by controlled air addition to burn out the balance of the fuel.

The rich fireball concept for tangentially fired boilers is the basis for ABB-CE's Low NO_x Concentric Firing System, the most commonly used low NO_x combustion system offered today for tangentially fired boilers. The cover shows the conceptual design of the rich fireball and its implementation in a full-scale boiler.[2] In this concept, part of the combustion air is diverted toward the furnace walls to create an internal fuelrich central core. Two EPA/CE retrofit demonstrations at 400 and 180 MW have produced NO_x levels of 0.41 and 0.35 lb/10^6 Btu (0.20 and 0.17 kg/kJ), respectively.[3,4] The Distributed Mixing Burner (DMB) for wall-fired boilers is shown in an artist's cutaway in Figure 1. In this concept, part of the combustion air is introduced through tertiary ports to create a fuel-rich flame zone. The concept can be adapted to a variety of burner designs; however, the burner shown is a generic design with a divided secondary air throat. The DMB is the result of an EPA development program that resulted in the design of a burner now commercially offered by the German firm L & C Steinmuller GmbH, which has achieved NO_x levels of about 0.4 lb/10^6 Btu on a 700 MW retrofit boiler. The development program also provided a wealth of data on the design and operational behavior of low NO_x burners for wall-fired boilers, forming much of the technical foundation for the evolution of today's advanced burners. EPA was also a major sponsor of the developmental efforts that led to the XCL burner (shown in Figure 2) now offered by Babcock & Wilcox as the heart of their most advanced low NO_x combustion system.[5] This burner is based on the Babcock & Wilcox Dual Register Burner (DRB) with air velocities and fuel injector designs optimized as part of the Limestone Injection Multistage Burner (LIMB) demonstration at Ohio Edison Edgewater's 108 MW boiler. The designs were optimized to accommodate short firing depths and limited fan pressures. During the demonstration, the burner achieved an emission rate of 0.48 lb/10^6 Btu (0.23 kg/kJ).[5]

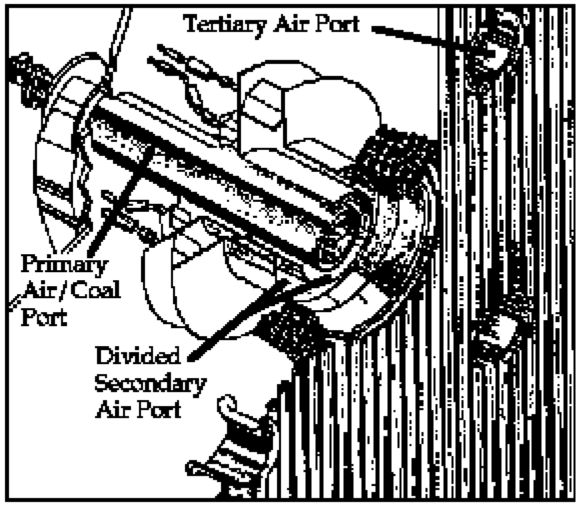


Figure 1. Artist's cutaway view of the Distributed Mixing Burner (DMB).

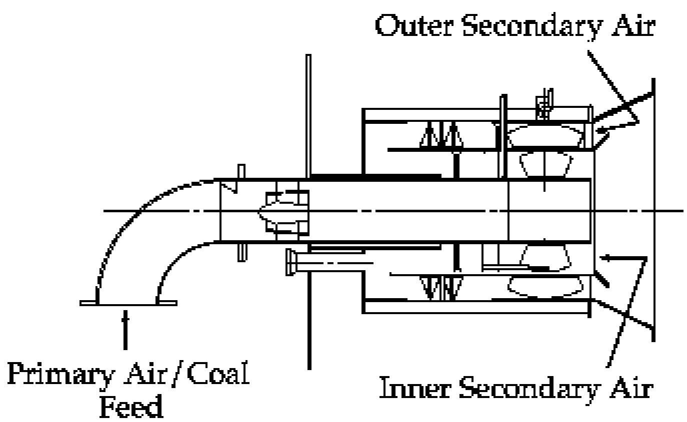


Figure 2. Schematic drawing of the Babcock & Wilcox XCL Burner.[5] A coal impeller may also be added in the primary burner barrel to accommodate short firing depths.

EPA also played a significant role in the development of another NO_x control technology, natural gas reburning. Reburning injects fuel, usually natural gas, downstream of the primary combustion zone both to provide a portion of the total heat input (usually less than 15%) and to destroy NO formed within the primary zone. The foremost advantage of reburning (or "fuel staging") is its ability to be used in applications where air staging or low NO_x burners are not possible, such as in wet bottom boilers that cannot operate at the lower furnace temperatures often caused by staging without "freezing" the liquid slag formed during the combustion process. Reburning has recently been demonstrated in two full-scale utility boilers under EPA cosponsorship. The demonstration project at Ohio Edison's Niles plant provided long term operational data on the use of natural gas reburning on a 108 MW cyclone boiler. A 300 MW wet bottom wall-fired boiler in Ukraine (see Figure 3) was also the site of an AEERL demonstration of natural gas reburning. AEERL, with ABB-CE, provided the conceptual design for the system. The final engineering drawings were produced by the All Russian Heat

Engineering Institute in Moscow, and the system was installed on a boiler at the Ladyzhinskaya power station south of Kiev in Ukraine. On both units, NO_x reductions of up to 50% were common at full load conditions.[6,7]

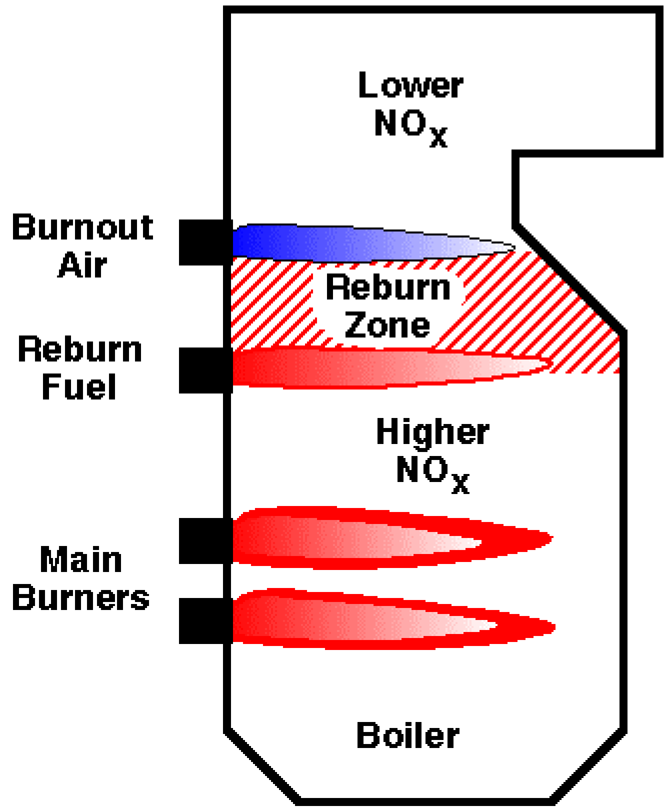


Figure 3. Conceptual design of the reburn system installed in Ukraine as part of a joint EPA-Russia-Ukraine project.

Technology Transfer

As an outgrowth of the NO_x program, EPA has held, and continues to hold, a series of technical meetings to relay information to industry and other researchers. The first meeting that was national in scope was the Stationary Source Combustion Symposium, held in 1975. From this meeting, a biannual series of symposia have been sponsored by EPA. Starting with the 1980 symposium, sponsorship has been joint with the Electric Power Research Institute (EPRI), and the NO_x symposia have become the major NO_x control technology forums worldwide. The ninth Joint Symposium on Stationary Combustion NO_x Control was held in May 1993, and attracted over 500 attendees from government, industry, and the research community from the U.S. and six other countries. In addition to information on utility boiler NO_x control, the symposia have presented information on fundamental NO_x formation and destruction mechanisms, control of industrial sources, and regulatory impacts on cost and performance. In addition to the symposia, transfer of technical information has taken place through the publication of symposia proceedings and over 200 EPA technical reports and conference papers on topics including descriptions of fundamental NO_x formation and destruction mechanisms, emissions from low

NO_x burners for residential furnaces, and combustion modification techniques for full-scale utility boilers.

Program Impact

Much of EPA's research and development effort on combustion modification NO_x control focused on fundamental and pre-commercial science and technology development; the end result of EPA sponsored work is therefore indirect and difficult to quantify precisely. However, these efforts provided, at a minimum, critical developmental seeds for four commercially available low NO_x burner systems: the Babcock & Wilcox XCL burner, with over 11,000 MW of burner capacity under contract; ABB-CE's Low NO_x Concentric Firing System and the tangential low NO_x combustion system offered by NEI, with 25,000 MW of planned or installed capacity; and Steinmuller's staged mixing burner, with over 25,000 MW of installed capacity overseas. At an average estimated cost of $20 per installed kilowatt, the value of these systems is over $1.2 billion.

The AEERL has conducted an active combustion modification control technology research and development program since 1975. The NSPS for NO_x from utility boilers resulting in part from these efforts have yielded a reduction of NO_x emissions of approximately 1 million tons per year from utility units alone since 1985. Over 250,000 MW of utility generating capacity will use some form of combustion modification NO_x control to meet the Title IV NO_x reduction provisions of the CAAAs. Prior to the passage of the CAAAs, the NSPS were the primary form of national NO_x emissions regulations for both utility and industrial sources. The impacts of the NSPS are clearly seen in Figure 4 by the drop in the rate of increase of national NO_x emissions following promulgation of the NSPS requirements in 1971 and 1977. The average national NO_x emission factor from coal-fired utility boilers has been reduced from 0.97 lb/million Btu (0.46 kg/kJ) in 1970 to approximately 0.83 lb/10^6 Btu (0.40 kg/kJ) in 1992, and will be lowered to below 0.50 lb/10^6 Btu (0.24 kg/kJ) after the year 2000 when the NO_x provisions of the CAAAs take effect.[8-10] While some of the emissions reductions can be ascribed to increased efficiency and lower electricity consumption, these reductions would not have been possible without the regulations on new sources; these regulations, in turn, were made possible to a large degree through the efforts of EPA in the area of NO_x control technology research and development.

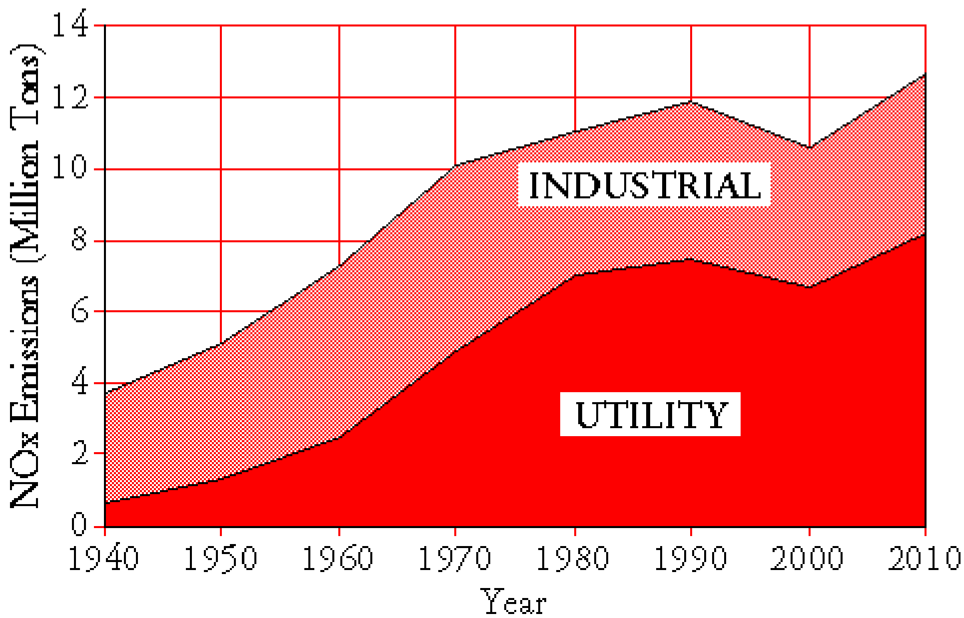


Figure 4. National emissions of NO_x from utility and industrial sources, 1940-2010 (actual and projected).[8-10]

Not only have the designs of new units incorporated the results of EPA's research and development efforts, but the emissions levels mandated by the CAAAs are a direct result of EPA's work to develop burner technologies which can be retrofitted to boilers built prior to the NSPS. Title IV of the CAAAs set a Phase I goal of an annual reduction in NO_x emissions from utility boilers of 2 million tons for the purpose of minimizing acid deposition. The emission rates of 0.45 lb/10^6 Btu (0.22 kg/kJ) for tangentially fired boilers and 0.50 lb/10^6 Btu (0.24 kg/kJ) for wall-fired boilers were based to a large degree on the performance of EPA-sponsored retrofit control technology. Additional reductions are expected to be attained by the mandated controls associated with Phase II of Section 407 of the CAAAs. Annual costs associated with the Phase I controls have been estimated at less than $3 per electric customer, less than the cost of one meal at a typical fast-food restaurant.

In addition to these reductions, Title I of the CAAAs requires control of NO_x for the purpose of reducing ambient ozone levels in certain areas of the country. Emission standards for Title I are typically lower than those for Title IV; both of these programs are possible in large part because of the advances in fundamental combustion science and technology development sponsored or conducted by EPA.

Current combustion modification NO_x control research is focused on methods to enhance reburn technology. Existing reburn technology is capable of achieving 50% NO_x reduction with 15 to 18% of the total heat input in the natural gas reburn fuel. EPA is exploring ways to obtain higher levels of NO_x control or to minimize the amount of reburn fuel needed to obtain current levels of NO_x reduction. Potential methods being considered include pulsed combustion, controlled mixing of the reburn fuel with the furnace gases, water injection, ammonia injection, or alternative reburn fuels. Promising techniques may be tested on full-scale boilers in the U.S., Russia, or Ukraine.

Future research will likely focus on application of combustion modification (CM) technology to industrial boilers, which account currently for 28% of stationary source NO_x emissions. In addition, CM combined with Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) will be studied. Some flue gas treatment processes which reduce NO_x can create N_2O, a greenhouse and ozone-depleting gas. EPA's combustion NO_x control research program is well positioned to help mitigate this problem.

In conclusion, advances in fundamental science, application development, and full-scale technology application associated with NO_x control have led to major decreases in the total emissions of NO_x from stationary combustion sources, and EPA has played a major role in each of these areas. The NO_x reduction emissions due to these advances continue to benefit the health and environment of the people of the U.S. and many other parts of the world.

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